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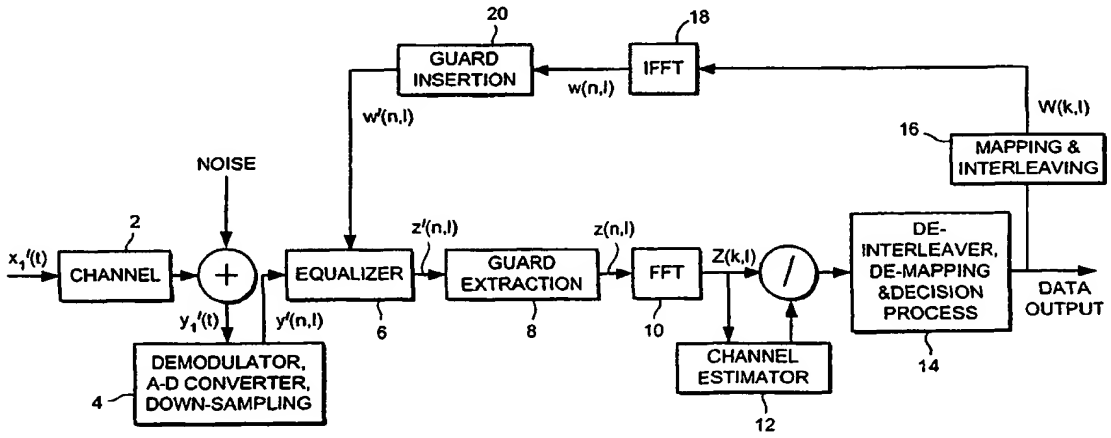

(57) Abstract

An OFDM receiver includes an adaptive equalizer, which acts on a received signal, after conversion to digital samples. After filtering by the equalizer, any guard interval is removed, and a Fast Fourier Transform is applied to the signal. The data signal is then estimated and the estimated data is supplied as an output. The estimated data also has any guard interval reinserted, and is applied to an Inverse Fast Fourier Transform, and is fed back to the equalizer to allow adaptation of the tap coefficients thereof.

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INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 00/00174

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H04L27/26 H04L25/03

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H04L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 796 814 A (BRAJAL AMERICO ET AL) 18 August 1998 (1998-08-18) the whole document	1-9
A	EP 0 797 333 A (TELEDIFFUSION FSE ;FRANCE TELECOM (FR)) 24 September 1997 (1997-09-24) abstract page 5, line 29 -page 6, line 46; figure 3	1-9
A	US 5 285 474 A (CHOW JACKY ET AL) 8 February 1994 (1994-02-08)	1-9

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[X] Further documents are listed in the continuation of box C.

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Date of the actual completion of the international search	Date of mailing of the international search report
17 April 2000	02/05/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Koukourlis, S

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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
P,X	ARMOUR S ET AL: "Pre-FFT equaliser design for OFDM" ELECTRONICS LETTERS, vol. 35, no. 7, 1 April 1999 (1999-04-01), pages 539-540, XP002135846 UK ISSN: 0013-5194 the whole document	1-9
P,X	ARMOUR S ET AL: "Performance analysis of a pre-FFT equalizer design for DVB-T" IEEE TRANSACTIONS ON CONSUMER ELECTRONICS, vol. 45, no. 3, August 1999 (1999-08), pages 544-552, XP002135847 New York, USA ISSN: 0098-3063 the whole document	1-9
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INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/GB 00/00174

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OFDM RECEIVER WITH ADAPTIVE EQUALISER

This invention relates to a receiver, and in particular to an OFDM receiver, and to an adaptive equalizer for use in such a receiver and to a method of training the equalizer.

The European digital terrestrial television standard, DVB-T, specifies orthogonal frequency division multiplexing, OFDM as the modulation scheme.

In conventional OFDM systems, multipath radio transmission channels cause delay spread distortion of the transmitted signal. Although adaptive equalizers can be used in many applications to cancel out delay spread distortion, existing designs for OFDM receivers and adaptive equalizers are generally incompatible, although it has been proposed to use a number of equalizers acting in parallel on respective sub-bands of the OFDM signal.

Therefore, existing designs for OFDM systems employ guard intervals to combat the effects of delay spread. Each transmission period includes a period during which useful information is transmitted, and a guard interval, during which no useful information is transmitted. Thus, use of a guard interval reduces efficiency of the transmission, and less data can be transmitted within a given radio frequency bandwidth.

The present invention relates to an OFDM receiver including an adaptive equalizer, which attempts to overcome the incompatibility of existing designs of OFDM receivers and adaptive equalizers.

According to a first aspect of the present invention, there is therefore provided a receiver as defined in claim 1.

According to a second aspect of the present invention, there is therefore provided an equalizer as defined in claim 6.

According to a third aspect of the present invention, there is therefore provided a method as defined in claim 7.

For a better understanding of the present invention, reference will now be made to the accompanying drawings, in which:-

Figure 1 shows a first receiver in accordance with the invention;

Figure 2 shows a first equalizer in accordance with the invention;

Figure 3 shows a second equalizer in accordance with the invention;

Figure 4 shows a second receiver in accordance with the invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

As Shown in Figure 1, a transmitted analog OFDM symbol is received over a radio frequency channel 2 having unknown and time-varying characteristics, and is subject to the addition of noise.

The receiver therefore takes an input signal $y_1'(t)$ in an input device 4, where it is demodulated, A-D converted and down-sampled to give a time domain vector $y'(n,l)$. The received sequence $y'(n,l)$ is filtered by an adaptive equalizer 6 to produce a time-domain sequence $z'(n,l)$.

The time domain sequence output from the equalizing filter 6 is input to a guard extraction device 8 to form an output $z(n,l)$, An advantage of the present invention is that the need for a guard interval may be reduced or eliminated. The guard extraction device 8 is therefore required only if it is needed if a guard interval is used by the transmitter which is in use.

A Fast Fourier Transform (FFT) 10 is then applied to $z(n,l)$ to produce a frequency domain vector $Z(k,l)$.

In this embodiment of the invention, the frequency

domain vector is supplied to a channel estimator 12 which derives an estimation of the radio channel's frequency response and compensates according to this estimate. In an alternative embodiment, the channel estimator may be omitted.

The vector is then supplied to an output device 14 to produce a data output. The output device 14 may be nothing more than a hard limiter, putting the data into a useable form. However, any interleaving, coding, signal mapping or other error control strategies applied in the transmitter are reversed in the output device 14 and exploited to correct any errors and produce the output data sequence. The output data, which is the best possible estimate of the data content of the transmitted signal is then applied to a feedback loop, and processed to form the best possible estimate of the transmitted sequence. Specifically, the data output is applied to a device 16 which interleaves, codes and maps the data in an identical manner to that performed at the transmitter to produce the frequency domain sequence $W(k,l)$.

The frequency domain sequence is input to an inverse Fourier transform device 18 and the output $w(n,l)$ of this device is applied to a guard interval insertion device 20 to insert a guard interval corresponding to any that was added in the transmitter to generate a sequence $w'(n,l)$. In effect, the data output is processed in the feedback loop to effectively attempt to reconstruct the OFDM symbol that was generated at the transmitter, and hence $w'(n,l)$ is an estimate of the transmitted sequence $x'(n,l)$.

The estimate $w'(n,l)$ is then input to the equalizing filter 6 to enable decision directed adaptation of the tap coefficients thereof.

Each updated estimate of an OFDM symbol, made up of a number of sub-symbols, is available to the

equalizer only after all sub-symbols of one OFDM symbol have been received.

Figure 2 shows the equalizer of the present invention. As is generally conventional, the equalizer consists of two shift register sections: a feedforward section 32 that stores future transmission symbols and the current transmission symbol and a feedback section 34 that stores previous transmission symbols. The length of the feedforward section is (J_1+1) symbols and the length of the feedback section is J2 symbols. The received sequence y'(n,l) is input, the value of each stored symbol is multiplied by a tap coefficient c(j), and the results are summed to form the equalizer output z'(n,l).

The tap coefficients c(j) are updated according to the LMS adaptation algorithm. As is known, the LMS algorithm adapts the equalizer taps according to the error measure between the equalizer output symbols and an estimate of the transmitted symbols. The estimate of the transmitted symbols can be achieved either by means of a training sequence or by decision directed adaptation.

Adaptation according to a training sequence requires the transmission of symbols of which the equalizer has prior knowledge. This training mode allows adaptation according to an error free estimate of transmitted symbols but results in no data throughput.

Decision directed adaptation feeds back output data to estimate the transmitted symbols. This estimate is not necessarily error free but does allow for data throughput.

In practice, the two techniques are combined. An initial training sequence approximately adapts the equalizer and reduces equalizer output error sufficiently that decision directed adaptation may

provide an adequate error measurement for further adaptation. During decision directed adaptation the equalizer further adapts both to `fine tune' its action and to track any relatively small time variation in the radio channel.

The equalizer of Figure 2 is generally similar to a conventional equalizer, although there are differences as follows:-

Symbols input to the feedback register 32 during decision directed operation do not come directly from the decision device but rather from the feedback vector.

Symbols used to calculate error during decision directed operation come similarly from the feedback vector rather than direct from the decision device.

Additional buffers 36, 38 for both feedforward and feedback sections further store past symbols beyond the duration of the feedforward/feedback sections. These additional stored values are required for decision directed adaptation

During decision directed mode the tap coefficients are not updated at intervals of the sub-symbol period, but rather at the OFDM symbol period, regarding one OFDM symbol as made up a group of sub-symbols.

However, the LMS calculation is performed in the LMS calculation processor 40 to calculate adjustments corresponding to intervals of the sub-symbol period with the sum of all calculated adjustments being made at intervals of the OFDM symbol period.

The equalizer output may be directly input to the feedback section thereof.

These additional features, which apply during a decision directed (or data derived) operation, enable the equalizer to operate within the OFDM receiver architecture.

More detailed explanation of all these features is

given below.

Since the equalizer operates on the received time domain sequence its output is also a time domain sequence. Data in the OFDM modem is in the frequency domain and hence the equalizer output must be Fourier Transformed (with any guard interval first being removed) prior to the decision process. Thus, the output of the equalizer cannot be applied directly to the decision device. Similarly the decision device output cannot be fed back directly to the equalizer. The feedback vector is fed back instead. If the equalizer is adapting according to a training sequence this is irrelevant, since the training sequence itself is an error free estimate of the transmitted sequence and can be input to the equalizer's feedback section. Furthermore, the decision device output cannot be used to calculate the output error used in the LMS adaptation algorithm and the feedback vector is again used instead.

The additional symbol buffering and the changes to the adaptation process in decision directed mode are necessary since the parallel transmission undertaken in OFDM results in the group post-decision data sub-symbols making up one OFDM symbol being simultaneously output at intervals of the OFDM symbol period. (By contrast, a single carrier system outputs individual symbols at intervals of the symbol period.) This restriction imposed by the parallel transmission prevents decision directed adaptation during OFDM symbols. It also prevents feedback values becoming available to the equalizer until the end of the OFDM symbol.

Therefore, instead of adapting the equalizer with each transmission sub-symbol, all transmission symbols forming the OFDM symbol are clocked through the equalizer with the tap coefficients remaining constant

and the equalizer output is input directly into the feedback section. At the end of each OFDM symbol the past and future transmission symbols that were stored in the feedforward and feedback sections at the start of the OFDM symbol are recovered from the buffers. Since the tap coefficients remain constant throughout the OFDM symbol the equalizer is effectively returned to its state at the start of the OFDM symbol. The OFDM symbol is then clocked into the equalizer once more with the feedback OFDM symbol now available both for determination of error and input to the feedback section. This process enables the adaptation steps that had not previously taken place to be completed and replaces the fed back output symbols with post decision estimates of the transmitted symbols as provided by the feedback OFDM symbol.

This method of operation described above allows both the feedforward and feedback stages of the equalizer to have numbers of taps which are integer multiples of the length of the extended OFDM symbol, which is considered to be (N+M), with N the number of transmission symbols in the useful period of an OFDM symbol, and M the number of transmission symbols in the guard period. In this illustrated embodiment, these numbers of taps are equal to the length of the extended OFDM symbol.

The equalizer output is then given by:-

$$z'(n,l)=\sum_{j=-J_1}^{-J_1+n} c(j)\,y'((n-j-(N+M)),l+1)+\sum_{j=-J_1+n+1}^{0} c(j)\,y'((n-j),l)$$

$$+C_{out}(n)\sum_{j=1}^{n} c(j)\,z'((n-j),l)+\sum_{j=n+1}^{J_2} c(j)\,w'((n+(N+M)-j),l-1)$$

where:

$C_{out}(n)=0 \quad \text{for} \quad n=0$

and:

$C_{out}(n)=1 \quad \text{for} \quad n\neq 0$

The equalizer is then adapted according to the LMS algorithm, which in this case is defined as follows:-

During Training Mode:

$$c(j,n+1,l)=c(j,n,l)+\Delta\varepsilon'(n,l)y'^{*}((n-j-(N+M)),l+1)$$

for $-J_1 \le j \le -J_1+n+1$

$$c(j,n+1,l)=c(j,n,l)+\Delta\varepsilon'(n,l)y'^{*}((n-j),l)$$

for $-J_1+n+2 \le j \le 0$

$$c(j,n+1,l)=c(j,n,l)+\Delta\varepsilon'(n,l)x'^{*}((n-j),l)$$

for $1 \le j \le n$

$$c(j,n+1,l)=c(j,n,l)+\Delta\varepsilon'(n,l)x'^{*}((n+(N+M)-j),l-1)$$

for $n+1 \le j \le J_2$

$$\varepsilon'(n,l)=x'(n,l)-z'(n,l)$$

During Decision Directed Operation

$$c(j,n,l+1)=c(j,n,l)+C_{ff}(j)\sum_{n=0}^{N+M+j-1}\Delta\varepsilon'(n,l)y'((n-j),l)+\sum_{n=N+M+j}^{N+M-1}\Delta\varepsilon'(n,l)y'((n-(N+M)-j),l+1)$$

for $-J_1 \le j \le 0$

$$c(j,n,l+1)=c(j,n,l)+\sum_{n=0}^{j-1}\Delta\varepsilon'(n,l)w'((n+(N+M)-j),l-1)+C_{fb}(j)\sum_{n=j}^{N+M-1}\Delta\varepsilon'(n,l)w'((n-j),l)$$

for $1 \le j \le J_2$

$$\varepsilon'(n,l)=w'(n,l)-z'(n,l)$$

where:

$C_g(j) = 0$ for $-j = N + M$

and:

$C_g(j) = 1$ for $-j \neq N + M$

$C_g(j) = 0$ for $j = N + M$

and:

$C_g(j) = 1$ for $j \neq N + M$

Δ	Equalizer step constant
$c(j,n,l)$	Equalizer tap vector in OFDM system
$\varepsilon(n,l)$	Equalizer output error vector in OFDM system

Figure 3 shows an alternative equalizer in accordance with the invention. It corresponds generally to that of Figure 2, except that the symbols input to the equalizer's feedback section 34 are zero symbols. This prevents the feedback of noise bearing symbols into the equalizer but, as a consequence, the equalizer no longer cancels delay spread distortion from within the same OFDM symbol. However this will still allow for an effective transmission strategy since, for example, where a guard interval is employed, delay spread interference within the same OFDM symbol does not cause inter-carrier interference (ICI). Thus, an equalizer with zero symbol feedback may be combined with a channel estimation process to achieve cancellation of delay spread distortion without the need to feed back pre-decision transmission symbols.

Thus, in Figure 3, compared with Figure 2, the feedback path from the equalizer output directly to the feedback section is replaced by a zero symbol source.

The equalizer output then becomes:-

$C_{out}(n) = 0$, for all n.

The method of tap adaptation in the equalizer of figure 3 is the same as that described above with reference to Figure 2.

The equalizer is no longer required to cancel all delay spread distortion and hence the equalizer output is not expected to approximate the transmitted sequence. The receiver is therefore as shown in Figure 4, as the feedback vector must be adjusted to compensate the uncombatted distortion. This is achieved by reversing the channel compensation process in the feedback path. Thus the channel estimate produced by the channel estimator 12 is applied in reverse to the output of mapping and interleaving device 16. This achieves a feedback vector which is suitably adjusted.

There is thus described a receiver, and an equalizer, which allow adaptive equalization of OFDM signals, with a consequent improvement in the noise in the received signals.

CLAIMS

1. An OFDM receiver, comprising:

a received signal processor, for demodulating, A-D converting, and down-sampling received signals to form a time domain digital signal vector;

an equalizer, having at least a feedback section and having a plurality of tap coefficients, the equalizer acting on the time domain digital signal vector to form a filtered time domain sequence;

a Fast Fourier Transform processor, for acting on the filtered time domain sequence to form a frequency domain vector;

an output device, for converting the frequency domain vector into an output data signal;

an inverse Fast Fourier Transform processor, for acting on the output data signal to form an estimate of the transmitted sequence;

wherein the estimate of the transmitted sequence is supplied as an input to the equalizer to enable decision directed adaptation of the tap coefficients thereof, and further as an input to the feedback section of the equalizer.

2. An OFDM receiver as claimed in claim 1, further comprising:

a guard extraction device, for extracting any guard sequence from the filtered time domain sequence before processing by the Fast Fourier Transform processor; and

a guard insertion device, for inserting a guard interval, corresponding to that removed by the guard extraction device, into the estimate of the transmitted sequence supplied by the inverse Fast Fourier Transform processor.

3. An OFDM receiver as claimed in claim 1, further comprising:

a channel estimator, for compensating the frequency domain vector to produce a compensated frequency domain vector.

4. An OFDM receiver as claimed in claim 1, wherein the output device comprises means for exploiting and cancelling any error control strategies applied in a transmitter of the received signals, and further comprising:

means for reapplying to the output data signal any error control strategies cancelled in the output device.

5. An OFDM receiver as claimed in claim 4, wherein the output device comprises means for deinterleaving the compensated frequency domain vector.

6. An OFDM receiver as claimed in claim 4, wherein the output device comprises means for demapping the compensated frequency domain vector.

7. An adaptive decision feedback equalizer, comprising:

a first input, for a received signal comprising a plurality of symbols, the symbols representing an OFDM signal, each OFDM symbol comprising a plurality of sub-symbols per OFDM symbol period;

a feedforward stage, comprising a first number of taps and corresponding tap coefficients;

a feedback stage, comprising a second number of taps and corresponding tap coefficients;

a first buffer, for storing past symbols beyond symbols present in the feedforward stage;

a second buffer, for storing past symbols beyond symbols present in the feedback stage;

a correction algorithm processor, for updating tap coefficients of taps in the feedback stage and the feedforward stage at intervals of the OFDM symbol period.

8. A method of adapting coefficients of an

adaptive equalizer, the equalizer comprising:

a first input, for a received signal comprising a plurality of symbols, the symbols representing an OFDM signal, each OFDM symbol comprising a plurality of sub-symbols per OFDM symbol period;

a second input, for receiving a feedback signal comprising an estimate of a transmitted signal;

a feedforward stage, comprising a first number of taps and corresponding tap coefficients;

a feedback stage, comprising a second number of taps and corresponding tap coefficients;

a first buffer, for storing past symbols beyond symbols present in the feedforward stage;

a second buffer, for storing past symbols beyond symbols present in the feedback stage; and

a correction algorithm processor, for updating tap coefficients of taps in the feedback stage and the feedforward stage at intervals of the OFDM symbol period, the method comprising:

supplying the feedback signal to the second input once per symbol period;

calculating required corrections to the tap coefficients corresponding to intervals of the sub-symbol period; and

updating the tap coefficients of the taps at intervals of the OFDM symbol period based on all calculated corrections obtained during each said period.

9. A method as claimed in claim 8, further comprising outputting an equalized signal at intervals of the symbol period.

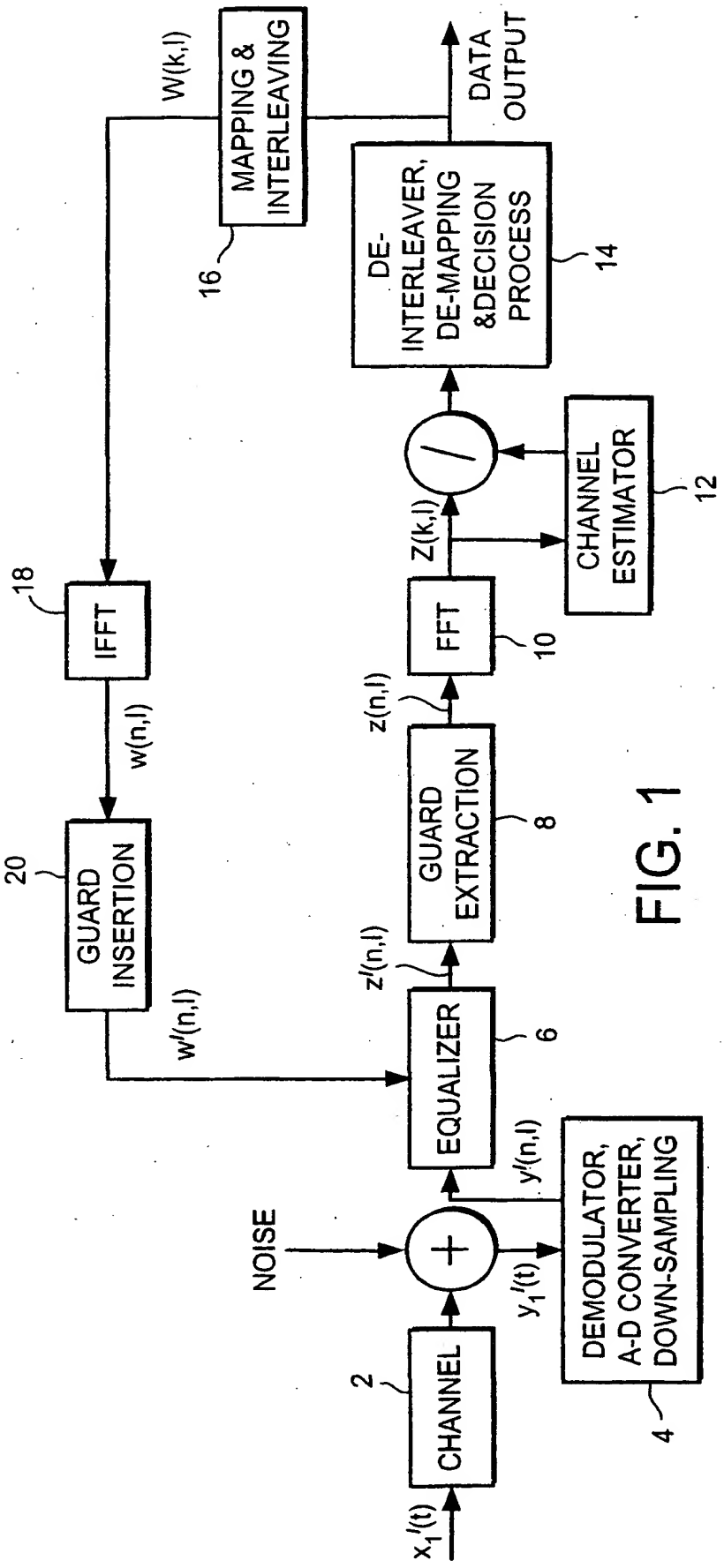
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FIG. 1

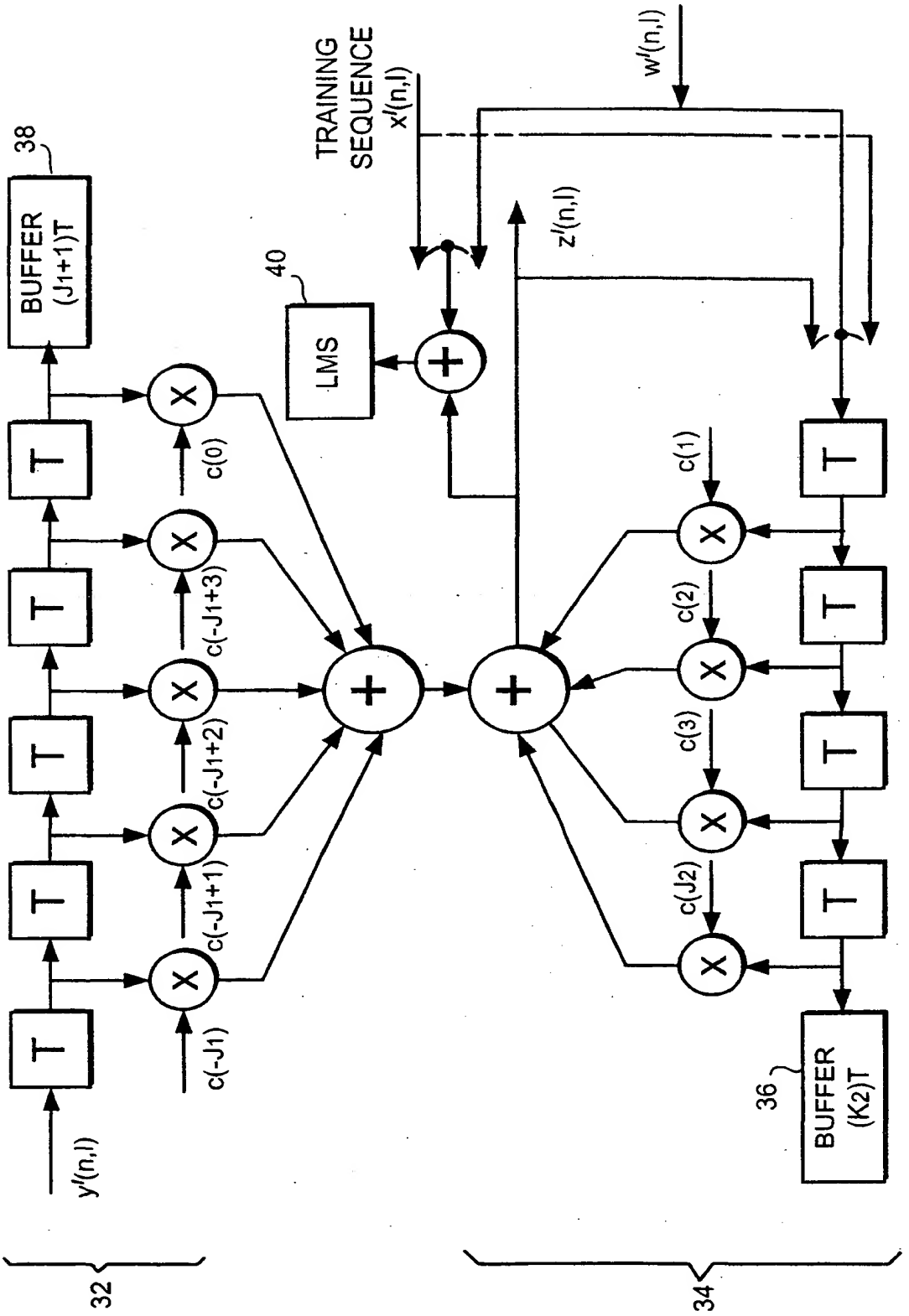
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FIG.2

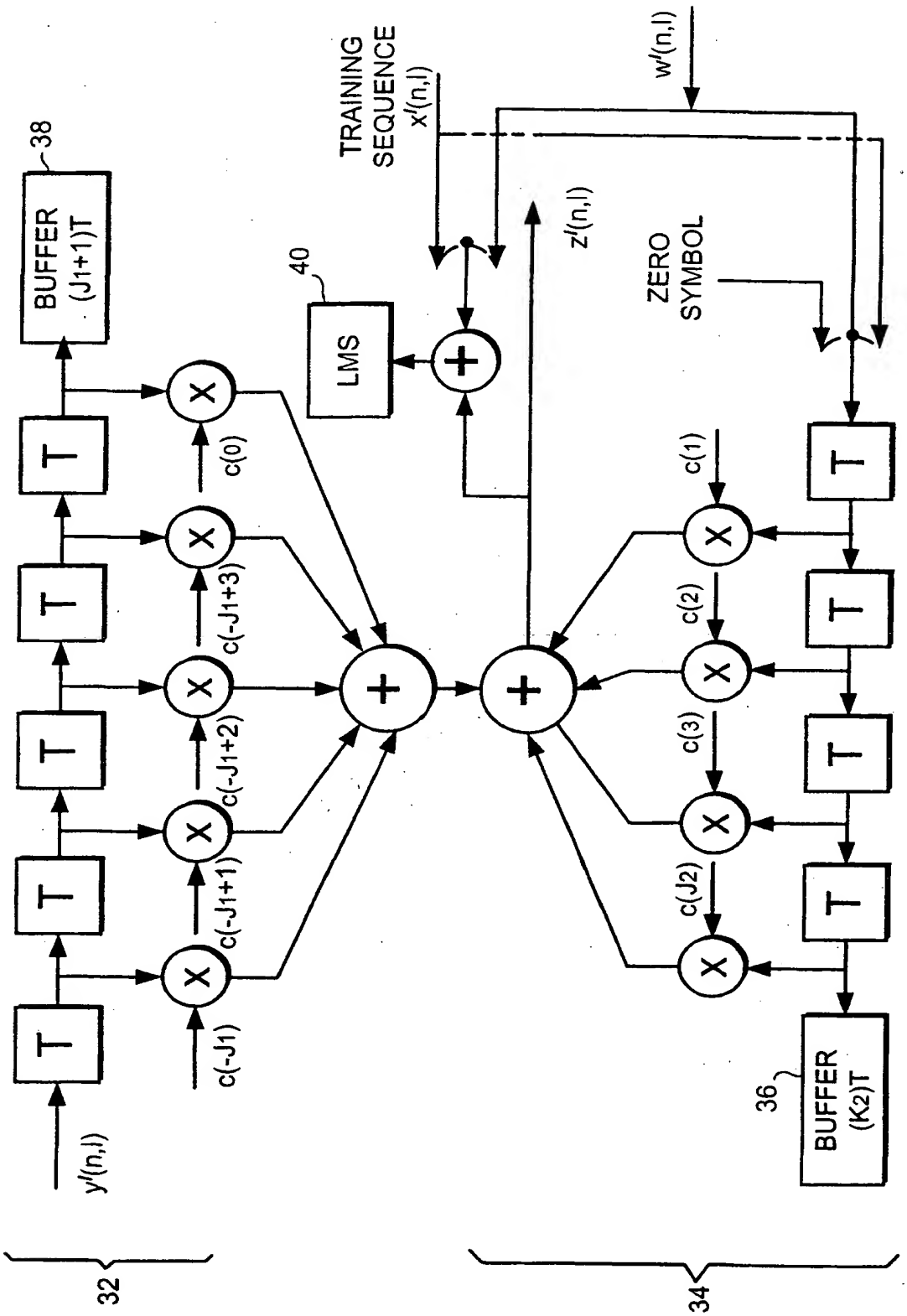
TRAINING SEQUENCE
x'(n,l)
w'(n,l)
z'(n,l)
ZERO SYMBOL
LMS
40
38
BUFFER (J1+1)T
36
BUFFER (K2)T
T
c(0)
c(-J1+3)
c(-J1+2)
c(-J1+1)
c(-J1)
c(1)
c(2)
c(3)
c(J2)
y'(n,l)
32
34

FIG. 3

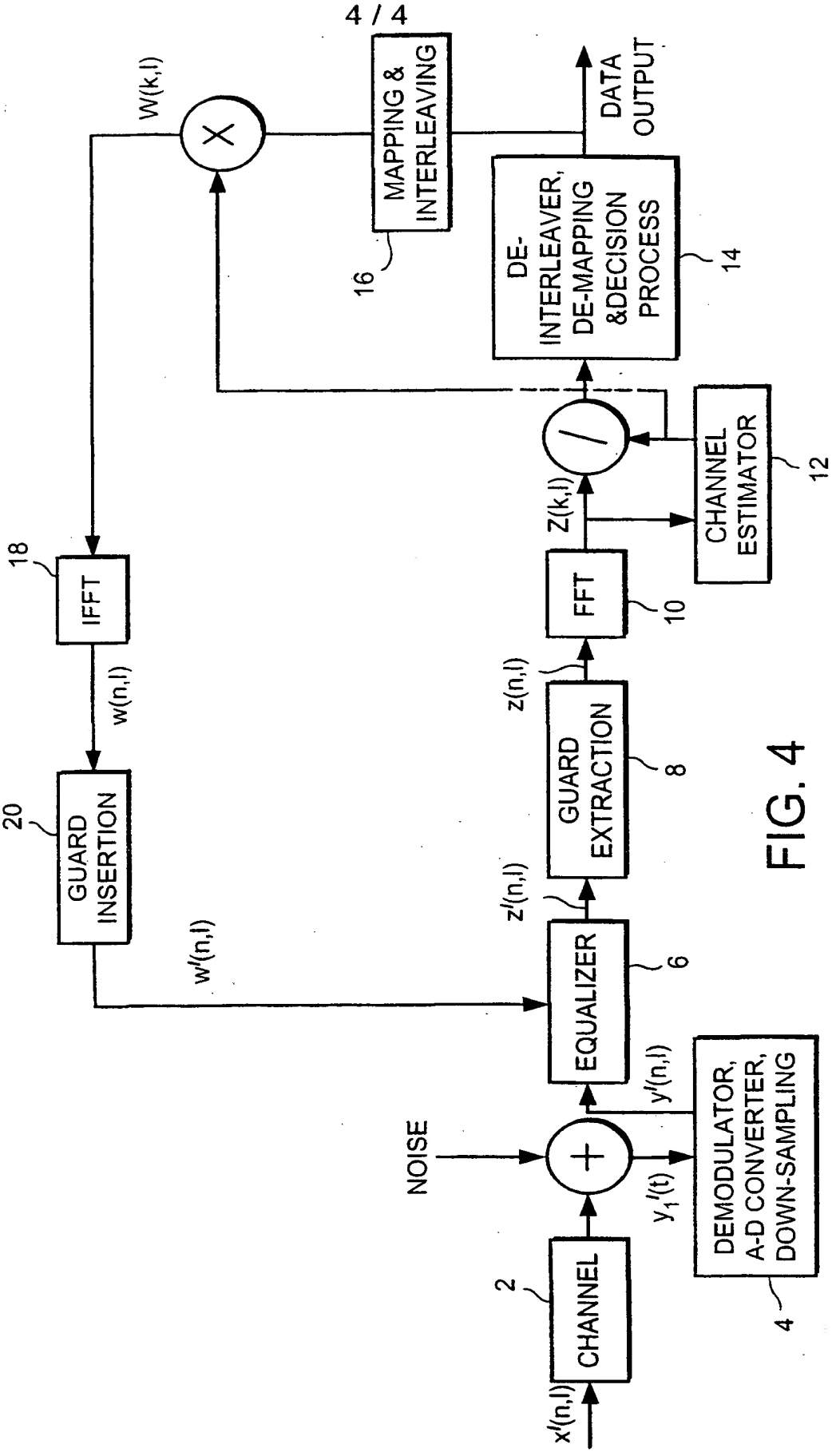
W(k,l)
MAPPING & INTERLEAVING
16
DATA OUTPUT
DE-INTERLEAVER, DE-MAPPING &DECISION PROCESS
14
CHANNEL ESTIMATOR
12
Z(k,l)
FFT
10
z(n,l)
GUARD EXTRACTION
8
z'(n,l)
EQUALIZER
6
y'(n,l)
DEMODULATOR, A-D CONVERTER, DOWN-SAMPLING
4
y1'(t)
NOISE
CHANNEL
2
x'(n,l)
18
IFFT
w(n,l)
20
GUARD INSERTION
w'(n,l)

FIG. 4

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 00/00174

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H04L27/26 H04L25/03

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H04L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 796 814 A (BRAJAL AMERICO ET AL) 18 August 1998 (1998-08-18) the whole document	1-9
A	EP 0 797 333 A (TELEDIFFUSION FSE ;FRANCE TELECOM (FR)) 24 September 1997 (1997-09-24) abstract page 5, line 29 -page 6, line 46; figure 3	1-9
A	US 5 285 474 A (CHOW JACKY ET AL) 8 February 1994 (1994-02-08)	1-9

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
17 April 2000	02/05/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	Koukourlis, S

Form PCT/ISA/210 (second sheet) (July 1992)

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
P,X	ARMOUR S ET AL: "Pre-FFT equaliser design for OFDM" ELECTRONICS LETTERS, vol. 35, no. 7, 1 April 1999 (1999-04-01), pages 539-540, XP002135846 UK ISSN: 0013-5194 the whole document	1-9
P,X	ARMOUR S ET AL: "Performance analysis of a pre-FFT equalizer design for DVB-T" IEEE TRANSACTIONS ON CONSUMER ELECTRONICS, vol. 45, no. 3, August 1999 (1999-08), pages 544-552, XP002135847 New York, USA ISSN: 0098-3063 the whole document	1-9
P,X	ARMOUR S ET AL: "Performance analysis of a pre-FFT equalizer design for DVB-T" 1999 DIGEST OF TECHNICAL PAPERS. INTERNATIONAL CONFERENCE ON CONSUMER ELECTRONICS (CAT. NO.99CH36277), LOS ANGELES, CA, USA, 22 - 24 June 1999, pages 72-73, XP002135848 Piscataway, NJ, USA ISBN: 0-7803-5123-1 the whole document	1-9
P,X	ARMOUR S ET AL: "The impact of FFT size on the performance of a combined OFDM-equalization radio modem" IEEE VTS 50TH VEHICULAR TECHNOLOGY CONFERENCE (CAT. NO.99CH36324), AMSTERDAM, pages 1506-1510 vol.3, XP002135849 Piscataway, NJ, USA ISBN: 0-7803-5435-4 the whole document	1-9

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/GB 00/00174

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5796814 A	18-08-1998	FR 2732178 A	27-09-1996
		EP 0734133 A	25-09-1996
		JP 8340315 A	24-12-1996
EP 0797333 A	24-09-1997	FR 2746238 A	19-09-1997
US 5285474 A	08-02-1994	AU 4411393 A	04-01-1994
		WO 9326096 A	23-12-1993

PCT

REQUEST

The undersigned requests that the present international application be processed according to the Patent Cooperation Treaty.

For receiving Office use only

International Application No.

International Filing Date

Name of receiving Office and "PCT International Application"

Applicant's or agent's file reference *(if desired) (12 characters maximum)* HL71607/000/DCO

Box No. I TITLE OF INVENTION

RECEIVER

Box No. II APPLICANT

Name and address: *(Family name followed by given name; for a legal entity, full official designation. The address must include postal code and name of country. The country of the address indicated in this Box is the applicant's State (that is, country) of residence if no State of residence is indicated below.)*

UNIVERSITY OF BRISTOL
Senate House
Tyndall Avenue
Bristol
BS8 1TH
United Kingdom

☐ This person is also inventor.

Telephone No.

Facsimile No.

Teleprinter No.

State *(that is, country)* of nationality: GB

State *(that is, country)* of residence: GB

This person is applicant for the purposes of: ☐ all designated States ☒ all designated States except the United States of America ☐ the United States of America only ☐ the States indicated in the Supplemental Box

Box No. III FURTHER APPLICANT(S) AND/OR (FURTHER) INVENTOR(S)

Name and address: *(Family name followed by given name; for a legal entity, full official designation. The address must include postal code and name of country. The country of the address indicated in this Box is the applicant's State (that is, country) of residence if no State of residence is indicated below.)*

ARMOUR, Simon
689 Wellsway
Odd Down
Bath
BA2 2TZ UNITED KINGDOM

This person is:

☐ applicant only

☒ applicant and inventor

☐ inventor only *(If this check-box is marked, do not fill in below.)*

State *(that is, country)* of nationality: GB

State *(that is, country)* of residence: GB

This person is applicant for the purposes of: ☐ all designated States ☐ all designated States except the United States of America ☒ the United States of America only ☐ the States indicated in the Supplemental Box

☒ Further applicants and/or (further) inventors are indicated on a continuation sheet.

Box No. IV AGENT OR COMMON REPRESENTATIVE; OR ADDRESS FOR CORRESPONDENCE

The person identified below is hereby/has been appointed to act on behalf of the applicant(s) before the competent International Authorities as: ☒ agent ☐ common representative

Name and address: *(Family name followed by given name; for a legal entity, full official designation. The address must include postal code and name of country.)*

O'CONNELL, David Christopher
HASELTINE LAKE & CO.
Imperial House
15-19 Kingsway
London
WC2B 6UD, United Kingdom

Telephone No. +44 (0) 171 420 0500

Facsimile No. +44 (0) 171 420 0505

Teleprinter No.

☐ **Address for correspondence:** Mark this check-box where no agent or common representative is/has been appointed and the space above is used instead to indicate a special address to which correspondence should be sent.

Continuation of Box No. III FURTHER APPLICANT(S) AND/OR (FURTHER) INVENTOR(S)

If none of the following sub-boxes is used, this sheet should not be included in the request.

Name and address: *(Family name followed by given name; for a legal entity, full official designation. The address must include postal code and name of country. The country of the address indicated in this Box is the applicant's State (that is, country) of residence if no State of residence is indicated below.)*

BULL, David Roger
Netherways
Netherhope Land
Tidenham
Nr. Chepstow
Monmouthshire, NP16 7JE United Kingdom

This person is:
- ☐ applicant only
- ☒ applicant and inventor
- ☐ inventor only *(If this check-box is marked, do not fill in below.)*

State *(that is, country)* of nationality: GB

State *(that is, country)* of residence: GB

This person is applicant for the purposes of: ☐ all designated States ☐ all designated States except the United States of America ☒ the United States of America only ☐ the States indicated in the Supplemental Box

Name and address: *(Family name followed by given name; for a legal entity, full official designation. The address must include postal code and name of country. The country of the address indicated in this Box is the applicant's State (that is, country) of residence if no State of residence is indicated below.)*

NIX, Andrew Robert
7 Bellview
Clifton
Bristol
BS8 1DA
United Kingdom

This person is:
- ☐ applicant only
- ☒ applicant and inventor
- ☐ inventor only *(If this check-box is marked, do not fill in below.)*

State *(that is, country)* of nationality: GB

State *(that is, country)* of residence: GB

This person is applicant for the purposes of: ☐ all designated States ☐ all designated States except the United States of America ☒ the United States of America only ☐ the States indicated in the Supplemental Box

Name and address: *(Family name followed by given name; for a legal entity, full official designation. The address must include postal code and name of country. The country of the address indicated in this Box is the applicant's State (that is, country) of residence if no State of residence is indicated below.)*

This person is:
- ☐ applicant only
- ☐ applicant and inventor
- ☐ inventor only *(If this check-box is marked, do not fill in below.)*

State *(that is, country)* of nationality:

State *(that is, country)* of residence:

This person is applicant for the purposes of: ☐ all designated States ☐ all designated States except the United States of America ☐ the United States of America only ☐ the States indicated in the Supplemental Box

Name and address: *(Family name followed by given name; for a legal entity, full official designation. The address must include postal code and name of country. The country of the address indicated in this Box is the applicant's State (that is, country) of residence if no State of residence is indicated below.)*

This person is:
- ☐ applicant only
- ☐ applicant and inventor
- ☐ inventor only *(If this check-box is marked, do not fill in below.)*

State *(that is, country)* of nationality:

State *(that is, country)* of residence:

This person is applicant for the purposes of: ☐ all designated States ☐ all designated States except the United States of America ☐ the United States of America only ☐ the States indicated in the Supplemental Box

☐ Further applicants and/or (further) inventors are indicated on another continuation sheet.

Box No. V DESIGNATION OF STATES

The following designations are hereby made under Rule 4.9(a) *(mark the applicable check-boxes; at least one must be marked)*:

Regional Patent

☒ **AP** **ARIPO Patent:** **GH** Ghana, **GM** Gambia, **KE** Kenya, **LS** Lesotho, **MW** Malawi, **SD** Sudan, **SL** Sierra Leone, **SZ** Swaziland, **TZ** United Republic of Tanzania, **UG** Uganda, **ZW** Zimbabwe, and any other State which is a Contracting State of the Harare Protocol and of the PCT

☒ **EA** **Eurasian Patent:** **AM** Armenia, **AZ** Azerbaijan, **BY** Belarus, **KG** Kyrgyzstan, **KZ** Kazakhstan, **MD** Republic of Moldova, **RU** Russian Federation, **TJ** Tajikistan, **TM** Turkmenistan, and any other State which is a Contracting State of the Eurasian Patent Convention and of the PCT

☒ **EP** **European Patent:** **AT** Austria, **BE** Belgium, **CH and LI** Switzerland and Liechtenstein, **CY** Cyprus, **DE** Germany, **DK** Denmark, **ES** Spain, **FI** Finland, **FR** France, **GB** United Kingdom, **GR** Greece, **IE** Ireland, **IT** Italy, **LU** Luxembourg, **MC** Monaco, **NL** Netherlands, **PT** Portugal, **SE** Sweden, and any other State which is a Contracting State of the European Patent Convention and of the PCT

☒ **OA** **OAPI Patent:** **BF** Burkina Faso, **BJ** Benin, **CF** Central African Republic, **CG** Congo, **CI** Côte d'Ivoire, **CM** Cameroon, **GA** Gabon, **GN** Guinea, **GW** Guinea-Bissau, **ML** Mali, **MR** Mauritania, **NE** Niger, **SN** Senegal, **TD** Chad, **TG** Togo, and any other State which is a member State of OAPI and a Contracting State of the PCT *(if other kind of protection or treatment desired, specify on dotted line)* .....

National Patent *(if other kind of protection or treatment desired, specify on dotted line)*:

☒ **AE** United Arab Emirates
☒ **AL** Albania
☒ **AM** Armenia
☒ **AT** Austria
☒ **AU** Australia
☒ **AZ** Azerbaijan
☒ **BA** Bosnia and Herzegovina
☒ **BB** Barbados
☒ **BG** Bulgaria
☒ **BR** Brazil
☒ **BY** Belarus
☒ **CA** Canada
☒ **CH and LI** Switzerland and Liechtenstein
☒ **CN** China
☒ **CR** Costa Rica
☒ **CU** Cuba
☒ **CZ** Czech Republic
☒ **DE** Germany
☒ **DK** Denmark
☒ **DM** Dominica
☒ **EE** Estonia
☒ **ES** Spain
☒ **FI** Finland
☒ **GB** United Kingdom
☒ **GD** Grenada
☒ **GE** Georgia
☒ **GH** Ghana
☒ **GM** Gambia
☒ **HR** Croatia
☒ **HU** Hungary
☒ **ID** Indonesia
☒ **IL** Israel
☒ **IN** India
☒ **IS** Iceland
☒ **JP** Japan
☒ **KE** Kenya
☒ **KG** Kyrgyzstan
☒ **KP** Democratic People's Republic of Korea
☒ **KR** Republic of Korea
☒ **KZ** Kazakhstan
☒ **LC** Saint Lucia
☒ **LK** Sri Lanka
☒ **LR** Liberia
☒ **LS** Lesotho
☒ **LT** Lithuania
☒ **LU** Luxembourg
☒ **LV** Latvia
☒ **MA** Morocco
☒ **MD** Republic of Moldova
☒ **MG** Madagascar
☒ **MK** The former Yugoslav Republic of Macedonia
☒ **MN** Mongolia
☒ **MW** Malawi
☒ **MX** Mexico
☒ **NO** Norway
☒ **NZ** New Zealand
☒ **PL** Poland
☒ **PT** Portugal
☒ **RO** Romania
☒ **RU** Russian Federation
☒ **SD** Sudan
☒ **SE** Sweden
☒ **SG** Singapore
☒ **SI** Slovenia
☒ **SK** Slovakia
☒ **SL** Sierra Leone
☒ **TJ** Tajikistan
☒ **TM** Turkmenistan
☒ **TR** Turkey
☒ **TT** Trinidad and Tobago
☒ **TZ** United Republic of Tanzania
☒ **UA** Ukraine
☒ **UG** Uganda
☒ **US** United States of America
☒ **UZ** Uzbekistan
☒ **VN** Viet Nam
☒ **YU** Yugoslavia
☒ **ZA** South Africa
☒ **ZW** Zimbabwe

Check-boxes reserved for designating States which have become party to the PCT after issuance of this sheet:

☒ And all other states bound by the PCT since January 2000

Precautionary Designation Statement: In addition to the designations made above, the applicant also makes under Rule 4.9(b) all other designations which would be permitted under the PCT except any designation(s) indicated in the Supplemental Box as being excluded from the scope of this statement. The applicant declares that those additional designations are subject to confirmation and that any designation which is not confirmed before the expiration of 15 months from the priority date is to be regarded as withdrawn by the applicant at the expiration of that time limit. *(Confirmation (including fees) must reach the receiving Office within the 15-month time limit.)*

Box No. VI PRIORITY CLAIM ☐ Further priority claims are indicated in the Supplemental Box.

Filing date of earlier application (day/month/year)	Number of earlier application	Where earlier application is: national application: country	regional application:* regional Office	international application: receiving Office
item (1) 22/01/1999	9901491.2	GB		
item (2)				
item (3)				

☒ The receiving Office is requested to prepare and transmit to the International Bureau a certified copy of the earlier application(s) *(only if the earlier application was filed with the Office which for the purposes of the present international application is the receiving Office)* identified above as item(s): 1

** Where the earlier application is an ARIPO application, it is mandatory to indicate in the Supplemental Box at least one country party to the Paris Convention for the Protection of Industrial Property for which that earlier application was filed (Rule 4.10(b)(ii)). See Supplemental Box.*

Box No. VII INTERNATIONAL SEARCHING AUTHORITY

Choice of International Searching Authority (ISA) *(if two or more International Searching Authorities are competent to carry out the international search, indicate the Authority chosen; the two-letter code may be used)*: ISA /

Request to use results of earlier search; reference to that search *(if an earlier search has been carried out by or requested from the International Searching Authority)*: Date *(day/month/year)* Number Country *(or regional Office)*

Box No. VIII CHECK LIST; LANGUAGE OF FILING

This international application contains the following number of sheets:

request	4
description (excluding sequence listing part)	10
claims	3
abstract	1
drawings	4
sequence listing part of description	
Total number of sheets	22

This international application is accompanied by the item(s) marked below:

1. ☒ fee calculation sheet
2. ☐ separate signed power of attorney
3. ☒ copy of general power of attorney; reference number, if any:
4. ☐ statement explaining lack of signature
5. ☐ priority document(s) identified in Box No. VI as item(s):
6. ☐ translation of international application into (language):
7. ☐ separate indications concerning deposited microorganism or other biological material
8. ☐ nucleotide and/or amino acid sequence listing in computer readable form
9. ☐ other *(specify)*:

Figure of the drawings which should accompany the abstract:

Language of filing of the international application: ENGLISH

Box No. IX SIGNATURE OF APPLICANT OR AGENT

Next to each signature, indicate the name of the person signing and the capacity in which the person signs (if such capacity is not obvious from reading the request).

O'CONNELL, David Christopher
Authorised Representative

For receiving Office use only

1. Date of actual receipt of the purported international application:
2. Drawings: ☐ received: ☐ not received:
3. Corrected date of actual receipt due to later but timely received papers or drawings completing the purported international application:
4. Date of timely receipt of the required corrections under PCT Article 11(2):
5. International Searching Authority (if two or more are competent): ISA /
6. ☐ Transmittal of search copy delayed until search fee is paid.

For International Bureau use only

Date of receipt of the record copy by the International Bureau:

This sheet is not part of and does not count as a sheet of the international application.

PCT

FEE CALCULATION SHEET
Annex to the Request

For receiving Office use only

International application No.

Date stamp of the receiving Office

Applicant's or agent's file reference HL71607/000/DCO

Applicant
UNIVERSITY OF BRISTOL et al.

CALCULATION OF PRESCRIBED FEES

1. TRANSMITTAL FEE . . . . . 55 T

2. SEARCH FEE . . . . . 638 S

International search to be carried out by _____
(If two or more International Searching Authorities are competent in relation to the international application, indicate the name of the Authority which is chosen to carry out the international search.)

3. INTERNATIONAL FEE

Basic Fee
The international application contains 22 sheets.

first 30 sheets 264 b1

_____ x _____ = NIL b2
remaining sheets additional amount

Add amounts entered at b1 and b2 and enter total at B . . . . 264 B

Designation Fees
The international application contains ALL designations.

8 x 56 = 448 D
number of designation fees payable *(maximum 8)* amount of designation fee

Add amounts entered at B and D and enter total at I . . . . . 712 I

(Applicants from certain States are entitled to a reduction of 75% of the international fee. Where the applicant is (or all applicants are) so entitled, the total to be entered at I is 25% of the sum of the amounts entered at B and D.)

4. FEE FOR PRIORITY DOCUMENT *(if applicable)* . . . . . 22 P

5. TOTAL FEES PAYABLE . . . . . 1427 TOTAL
Add amounts entered at T, S, I and P, and enter total in the TOTAL box

☐ The designation fees are not paid at this time.

MODE OF PAYMENT

☐ authorization to charge deposit account (see below)
☐ bank draft
☐ coupons
☐ cheque
☐ cash
☐ other *(specify)*:
☐ postal money order
☐ revenue stamps

DEPOSIT ACCOUNT AUTHORIZATION *(this mode of payment may not be available at all receiving Offices)*

The RO/ _____ ☐ is hereby authorized to charge the total fees indicated above to my deposit account.

☐ *(this check-box may be marked only if the conditions for deposit accounts of the receiving Office so permit)* is hereby authorized to charge any deficiency or credit any overpayment in the total fees indicated above to my deposit account.

☐ is hereby authorized to charge the fee for preparation and transmittal of the priority document to the International Bureau of WIPO to my deposit account.

Deposit Account No. | Date *(day/month/year)* | Signature

See Notes to the fee calculation sheet

PATENT COOPERATION TREATY

PCT

INTERNATIONAL SEARCH REPORT

(PCT Article 18 and Rules 43 and 44)

Applicant's or agent's file reference	FOR FURTHER ACTION	see Notification of Transmittal of International Search Report (Form PCT/ISA/220) as well as, where applicable, item 5 below.
HL71607/000/DCO		
International application No.	International filing date *(day/month/year)*	(Earliest) Priority Date *(day/month/year)*
PCT/GB 00/ 00174	24/01/2000	22/01/1999
Applicant		
UNIVERSITY OF BRISTOL et al.		

This International Search Report has been prepared by this International Searching Authority and is transmitted to the applicant according to Article 18. A copy is being transmitted to the International Bureau.

This International Search Report consists of a total of 3 sheets.

[X] It is also accompanied by a copy of each prior art document cited in this report.

1. **Basis of the report**

   a. With regard to the **language,** the international search was carried out on the basis of the international application in the language in which it was filed, unless otherwise indicated under this item.

   [ ] the international search was carried out on the basis of a translation of the international application furnished to this Authority (Rule 23.1(b)).

   b. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international search was carried out on the basis of the sequence listing :

   [ ] contained in the international application in written form.

   [ ] filed together with the international application in computer readable form.

   [ ] furnished subsequently to this Authority in written form.

   [ ] furnished subsequently to this Authority in computer readble form.

   [ ] the statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.

   [ ] the statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished

2. [ ] **Certain claims were found unsearchable** (See Box I).

3. [ ] **Unity of invention is lacking** (see Box II).

4. With regard to the **title,**

   [ ] the text is approved as submitted by the applicant.

   [X] the text has been established by this Authority to read as follows:

   OFDM RECEIVER WITH ADAPTIVE EQUALISER

5. With regard to the **abstract,**

   [ ] the text is approved as submitted by the applicant.

   [X] the text has been established, according to Rule 38.2(b), by this Authority as it appears in Box III. The applicant may, within one month from the date of mailing of this international search report, submit comments to this Authority.

6. The figure of the **drawings** to be published with the abstract is Figure No. 1

   [ ] as suggested by the applicant.

   [X] because the applicant failed to suggest a figure.

   [ ] because this figure better characterizes the invention.

   [ ] None of the figures.

Box III TEXT OF THE ABSTRACT (Continuation of item 5 of the first sheet)

The absract is changed as follows:

Line 4: after "guard" delete "(signal)";
Line 4: after "guard" insert "(interval)";
Line 7: after "guard " delete "(signal)";
Line 7: after "guard" insert "(interval)".